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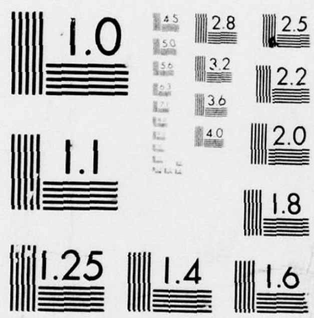

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BUFFET SIMULATION FOR ADVANCED SIMULATOR FOR PILOT TRAINING (ASPT)

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NOTICE

This final report was submitted by Flying Training Division, Air Force Human Resources Laboratory, Williams Air Force Base, Arizona 85224, under project 1123, with HQ Air Force Human Resources Laboratory (AFSC), Brooks Air Force Base, Texas 78235.

This technical report has been reviewed and is approved for publication.

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This paper presents a motion/control landing buffet simulation package as implemented on the Advanced Simulator for Pilot Training (ASPT) located at Williams AFB, Arizona. All primary buffet effects are included. The high level of pilot acceptance and subjective realism indicate a simplified approach to buffet simulation is sufficient for training purposes.

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PREFACE

This work was conducted in support of project 1123, task 112303; Mr. James F. Smith, Project Scientist; Mr. Mike Cyrus, Principal Investigator. This work was conducted by the Flying Training Division of the Air Force Human Resources Laboratory (AFSC), Williams Air Force Base, Arizona.

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BUFFET SIMULATION FOR ADVANCED SIMULATOR FOR PILOT TRAINING (ASPT)

I. INTRODUCTION

The Advanced Simulator for Pilot Training (ASPT) was delivered with a highly flexible motion system mathematical model designed to investigate various motion cueing possibilities and serve as a benchmark for future simulators. Included in this mathematical model was a standard Link buffet simulation including the following buffet effects: (a) speed brake buffet, (b) runway rumble, (c) landing gear down buffet, (d) landing gear in transit vibration, (e) landing gear down lock, (f) aerodynamic (stall) buffet, (g) touchdown bump, and (h) aerodynamic (rough air) buffet.

From the outset, however, pilots complained that the simulation lacked "realism" or was "distracting." Additionally, there was no stick and rudder (control) feedback vibration during stall (spin, etc.) which most pilots felt was "required" for training. Accordingly, Systems Engineering Branch, Flying Training (FT) Division, Air Force Human Resources Laboratory (AFHRL), conducted a subjective analysis of the buffet cues required for ASPT and developed simplified models for their implementation. These models were validated subjectively.

II. BUFFET CUE ANALYSIS

Method

Two AFHRL/FT T-37 research instructor pilots (IP) were asked to provide detailed information regarding the cue control for buffet effects (a) through (h) listed previously. They were asked for minimum response to the following four categories:

a. Frequency content

Identify factors contributing to the frequency content of the cue. What causes it to increase? Is it correlated with any other instrument or aerodynamic phenomenon?

b. Buffet magnitude content

As in (a), identify factors contributing to cue magnitude. Are magnitude and frequency related? If so, how?

c. Buffet direction

Does the buffet have any peculiar directional qualities or can it be noticed at all?

d. Buffet onset

Does the buffet onset directly to full magnitude, or does it build up? Is there any difference at all between initial buffet response (say entering stall for example) and later response (say, deep stall)? Additionally, the IPs were asked to add any other comments they felt would aid in the design of a better buffet simulation.

Results

The resulting information, from both pilots, with respect to both the Link system and suggested cue structure were virtually identical. The essential elements of that information for each effect is as follows:

a. Speed brake buffet

Three concepts were deemed appropriate for T-37 speedbrake simulation: onset (rise rate) control, frequency control, and magnitude control. Rise rate control was based on the opinion that approximately

80% of the full buffet magnitude occurs as soon as the speed brakes pop into the airstream, and rises from 80% to 100% prior to full speed brake deflections. Speed brake frequency control is a probabilistic function of indicated airspeed, increasing as airspeed increases. Magnitude control likewise varies directly with indicated airspeed.

b. Runway rumble

Runway rumble possesses both frequency and magnitude control. As the aircraft starts down the runway, "bumps" are spread wide apart and are relatively large in magnitude. As weight is lifted on the wheels, the magnitude decreases. Frequency increases with increasing airspeed. Pilots felt this approach would give some "texture" to the runway.

c. Landing gear down buffet

Pilots felt that the gear down buffet for a T-37 should be a low order magnitude buffet used to simulate air passing around the extended struts. Pilots felt that the magnitude, while small, should vary directly with indicated airspeed, although the explicit frequency content should remain fixed.

d. Landing gear intransit vibration

Similar to (c), this concept required explicit magnitude control only, in the opinion of the pilots. However, the "feel" is different since the combination of a modified magnitude response carries with it a different perception of frequency.

e. Landing gear down lock

This is a one time bump as the gear locks into place. Its magnitude is a fixed constant over the airspeed ranges wherein T-37 gear is lowered. Cue direction was not considered important.

f. Aerodynamic (stall) buffet

Buffet occurs in the T-37 aircraft approximately 4 to 10 knots above stall speed, depending on aircraft configuration, and gradually increases until it is heavy in full stall. Pilots felt they experienced stall not just in the airframe, but also in the controls (stick and rudder). Pilots felt that the airframe buffet frequency content was satisfactory as delivered. but that the magnitude content throughout the stall was improper. Coordination with control buffet was felt essential.

g. Touchdown bump

Although called "touchdown bump," the instructor pilots quickly reacted by saying that this buffet should be extended to touchdown effects for each wheel under a variety of surface friction conditions. Touchdown was considered a directional cue, with both translational and rotational components, whose magnitude varied directly with vertical velocity and whatever side velocities existed (such as occur when landing in a crab).

h. Aerodynamic (rough air) buffet

Of all the buffet cues generated by the original Link mathematical model, this one drew the least criticism. Only the relative earth velocity components were felt to be wrong. Additionally, pilots felt that some rolling buffet effects should also be generated. Frequency control was not considered a problem.

Motion Buffet Simulation

On the ASPT system, computer time is critical. ASPT was delivered with a primary motion output rate of 15 Hz, a primary computation rate of 7.5 Hz, and an interpolated output rate of 30 Hz. For that reason, a straight line, minimum time buffet module was desirable. However, three of the buffet cue types had to be handled separately: speed brake buffet, aerodynamic (stall) buffet, and aerodynamic (rough air) buffet. All others were placed in a 7.5 Hz motion buffet module.

For this module the buffet cues to be displayed are: (a) runway rumble, (b) landing gear down buffet, (c) landing gear in transit vibration, (d) landing gear down lock, and (e) touchdown bump.

The following concepts were employed:

1. Probabilistic magnitude and frequency response.
2. Only one buffet cue (of the five above) active per pass.
3. Buffet direction is reversed each iteration.

These concepts require some explanations. First, magnitude and frequency are controlled by the use of one or more calls to a random number generator. No digital filtering techniques are used to shape the frequency spectrum at all. For this module, the random number is biased to range from zero to two. Probabilistic control of magnitude then amounts to output of a linear function of the product of the random number and some aerodynamic variables. Although we control only the magnitude explicitly, it is clear that as the magnitude increases, so does the implicit frequency content (the frequencies that the pilot can feel). Similarly, frequency is controlled by comparing the product of the random number and some aerodynamic quantity (usually indicated airspeed) with a preset constant. The precise mathematical effect of this use is unknown to the authors, but the technique is very effective with execution time required. Only one buffet cue per pass was a loosely defined requirement. All of the five buffet cues controlled in this single motion module are separable. Reversing buffet direction each iteration makes better use of the available buffet capability. Buffet display on ASPT is not filtered as it is commanded to the leg cylinders; conceptually, it is similar to amplitude modulated signals: the buffet "rides" the primary motion command "carrier." Since the buffet cue structure was determined subjectively, and is not a "simulation" in the ordinary sense of the word, the actual constants we use on ASPT are not important; only the form of the mathematical model is. Implementation of this technique on any other simulator (for any other aircraft) would necessarily require different constants. Our implementation was as follows:

a. Runway rumble

$$\text{If } (a_1 v < r) \quad b = a_2 F_{Z_G} \tag{1}$$

Where a_1, a_2 are positive constants, V is indicated airspeed, in knots, and r is a uniformly distributed random number from zero to two. F_{Z_G} is the force in the z direction into the earth of the aircraft gear, and b is the resulting buffet amplitude. The buffet amplitude, b, is nominally zero each iteration as the module is entered. In the descriptions that follow, b, v, and r will retain their current meanings.

b. Landing gear down buffet

$$b = a_3 rv \tag{2}$$

Where a_3 is a positive constant.

c. Landing gear in transit vibration

$$b = a_4 rv \tag{3}$$

Where a_4 is a positive constant.

d. Landing gear down lock

$$b = a_5 \tag{4}$$

Where a_5 is a positive constant.

e. Touchdown bump

$$B = a_6 W_E \tag{5}$$

Where a_6 is a positive constant and W_E is the vertical velocity of the aircraft at touchdown. This simulation is the least satisfactory in the opinion of the authors. Although the touchdown bump produced

will cue the pilot as to whether or not he flared too high, or flew the aircraft onto the runway, this simulation lacks the "scrunch" feeling of touchdown which a more sophisticated display of the ground reaction forces involved would most likely produce.

Speed brake buffet and the two aerodynamic buffets required special handling. In the case of speed brake buffet, the 7.5 Hz primary motion buffet module could not generate sufficient sensation of high frequency content to be satisfactory to the pilots. The speed brake buffet was then placed in the primary motion output module, which executes at 15 Hz. This added capability proved more than adequate. The aerodynamic buffets both required more rigorous mathematical models. These buffets follow:

f. Speed brake buffet

$$\text{If } (\delta_{SB} < .01) \text{ exit} \tag{6}$$

$$\text{If } (a_7 r < v) \text{ exit}$$

$$a_8 = \min \{ .8 + \delta_{SB}, 1 \}$$

$$b = \max \{ a_9 v a_8 - a_{10}, 0 \}$$

Where $\dot{\delta}_{SB}$ is a number representing the degree to which the speed brakes are open (0 is closed, 1 is full open). All constants are positive and the direction of the buffet is reversed or set to zero, at 15 Hz. Speed brake buffet has both magnitude and frequency control. As soon as the speed brakes open (greater than 1%), buffet magnitude rises to 80% full scale. From there to 20% deflection, magnitude control is linear, remaining at 100% thereafter. The lower limiting speed brake vibrations refer to the fadeout of the vibration effect below 100 knots. Pilot reaction to this simple simulation has been very favorable.

g. Aerodynamic (stall) buffet

$$a_{11} = f\,(\text{configuration, angle of attack, mach}) \tag{7}$$

$$b = \min \{ \max \{ c_L - a_{11}, 0 \}, a_{12} \}$$

In this case, a_{11} is effectively a precomputed coefficient, a lift-like term with the random fluction built in and modelled based on aerodynamic data. The form of implementation is table look up. The second equation considers the difference the table look up and the actual aircraft lift coefficient and scales the resulting output to be between zero and a_{12}, with reversal of direction 7.5 times a second. The authors feel this model is still overly complex.

h. Aerodynamic (rough air) buffet

The rough air buffet is unusal in that it does not pass through the normal buffet channels, but is fed back into the equations of motion to generate forces. This simulation is the only Link delivered buffet which has remained unmodified except for scaling constants. The equations are implemented as follows:

$$b_{x_e} = a_{13} r$$

$$b_{y_e} = a_{14} r \tag{8}$$

$$b_{z_e} = a_{16} r$$

Where b_{x_e}, b_{y_e} and b_{z_e} are earth axis system components treated as velocities and summed into aircraft earth axis velocities. Due to the closed loop nature of the aerodynamic simulation, these inputs then effect angle of attack, lift and side force coefficients, etc., and reenter the buffet simulation as forces. Unfortunately, in the opinion of the authors, no rolling, pitching, or yawing movements of any kind are generated. While there has been no adverse comment regarding this simulation, we feel more work needs to be accomplished. As is the case with all other buffet types, no attempt has been made to imitate the gust spectral characteristics of the flight environment.

Control Loading Buffet Simulation

Aerodynamic (stall) buffet is the only form of buffet fed back to the controls of the simulator. The same basic equation used for stall buffet simulation in the motion system was used for feedback to the controls. The buffet components for the elevator and rudder are calculated at 15 Hz, using different values for a_{12} than as defined for motion buffet. The buffet components are added into the hinge force multipliers which are output to the simulator at 15 Hz. The net result is that the stick and rudder pedals buffet with a gradually increasing magnitude as the simulator approaches a deep stall, until the limiting magnitude is reached. The limiting values (a_{12}) were arrived at through subjective analysis by a number of T-37 instructor pilots.

III. CONCLUSIONS

We have presented a simple approach to buffet simulation, most of which has been used in training research studies successfully for more than a year. The mathematical models to present these special effects were based entirely on a detailed subjective analysis of buffet cueing. The authors feel that similar "structured" subjective analysis can lead to successful mathematical modeling in other areas of flight simulation.

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